DTU Library

The cold neutron source in DR3

Jensen, K.; Leth, J.A.

Publication date:
1980

Document Version
Publisher's PDF, also known as Version of record

RISØ-M-2246

THE COLD NEUTRON SOURCE IN DR 3

Knud Jensen and J.A. Leth

Abstract. A description of the cold neutron source in DR 3 is given. The moderator of the cold neutron source is supercritical hydrogen at about 30^{o}K and 15 bar abs. The necessary cooling capacity is supplied by two Philips Stirling B20 cryogenerators. The hydrogen is circulated between the cryogenerators and the in-pile moderator chamber by small fans. The safety of the facility is based on the use of triple containment preventing contact between hydrogen and air. The triple containment is achieved by enclosing the high vacuum system, surrounding the hydrogen system, in a helium blanket.

The achieved spectrum of the thermal neutron flux and the gain factor are given as well as the experience from more than 5 years of operation.

Finally some work on extension of the facility to operate two cold sources is reported.

INIS Descriptors
COLD NEUTRONS, DR 3 REACTOR,
GASES, HYDROGEN, NEUTRON FLUX,
NEUTRON SOURCES, OPERATION,
SAFETY, SPECIFICATIONS

UDC 539.125.5.03 : 621.039.524.46.034.46

September 1980
Risø National Laboratory, DK 4000 Roskilde, Denmark

ISBN 87-550-0708-2
ISSN 0418-6435

Risø repro 1980

CONTENTS

1. INTRODUCTION

1.1. Cold Neutrons

Cold neutrons may be defined as neutrons having energies below 5 meV, corresponding to de Broglie wavelengths longer than 4Å.

The average kinetic energy of fission neutrons is approximately 5 MeV. In a thermal reactor these fission neutrons are moderated to become thermal neutrons, mainly as a result of elastic scattering reactions with the moderator. The thermal neutron spectrum achieved is nearly a Maxwellian distribution corresponding to the moderator temperature. The average energy of the thermal neutrons is approximately 25 meV. Of the thermal neutrons only 1-2% have energies below 5 meV, i.e. are cold neutrons.

In order to obtain a higher cold neutron flux from an experimental hole, a chamber filled with a moderator which can be cooled to low temperatures is placed in the hole. For most cold neutron sources liquid hydrogen is chosen as moderating material.

Cold neutrons have longer wavelenghts than thermal neutrons, which makes them more suitable for investigations of structures with large atomic spacings. As examples may be mentioned structures of complex chemical combinations and molecules, structures and biochemical supermolecules, defects in crystals, and magnetic defects in magnetics alloys.

Because of wavelength - longer that 4Å - and velocity - below 1000 m/sec - cold neutron scattering has also proved a most useful method for dynamic investigations. As examples may be mentioned phonon life time, magnon life times, dynamics of magnetic phase transformations, diffusion in liquids, and molecular rotations, which because of symmetry characteristics cannot be studied by means of conventional methods.

1.2. General Description

In principle the cold neutron source in DR 3 consists of a hydrogen filled moderator chamber placed in the horizontal beam hole 7TL·3 of the reactor, see fig, 1. The moderator chamber and the hydrogen pipes are surrounded by a vacuum containment. The vacuum is used to insulate the cold parts, and the vacuum containment further acts as a second containment in a triple containment system, see 1.3. The annulus between the vacuum containment and the liner in the beam hole and the rest of the liner, are filled with helium at a small positive pressure.

Hydrogen is used as moderating material and as moderator chamber coolant at a pressure of 15 bar abs., which is above the critical pressure, see section 2. The hydrogen is circulated between the moderator chamber and the cryogenerators by means of a fan. The minimum moderator temperature is $28^{O}K$ corresponding to a heat load of about 600W at a reactor power of 10MW.

From an intermediated stage the cryogenerators may provide cooling at a nominal temperature of $80^{O}K$. This cooling capacity was in the beginning used to cool the neutron filters with a flow of cold helium circulated by a fan.

The cryogenerators are connected to the system through a joint box which contains fans, temperature sensors, and the cyogenic valves. The cryogenerators and the joint box are placed just above the beam hole. The moderator chamber and the cooling jacket for the neutron filter are connected to the joint box by means of transfer lines.

The only equipment placed outside the reactor shell, is the hydrogen buffer and supply system.

1.3. Safety Philosophy

Hydrogen alone is completely harmless, and a hazard only occurs, when oxygen is present too. The hydrogen/oxygen hazard may occur in two ways. Firstly, if some source of ignition is present, the elements combine exothermically to form water. Secondly, if oxygen from air is irradiated at cryogenic temperatures, ozone is formed and nitrogen may form oxides and ozonides of nitrogen which decompose explosively and initiate a hydrogen/oxygen reaction.

The basic principle for safety of the cold neutron source i DR 3 is to preclude any possibility, that air may enter either the hydrogen system or regions of the equipment containing hydrogen, especially at cryogenic temperatures and in fields of high radiation.

By adopting the triple-containment philosophy the abovementioned basic principle for safety is fulfilled. For the cold neutron source the triple containment philosophy is used for all hydrogen equipment inside the reactor shell, i.e. all hydrogen equipment is contained within a high-vacuum system, which is surrounded by a third containment filled with helium. The helium is always at a small positive pressure, so that a leak in the helium blanket can be detected.

Thus it is ensured that even in the event of a leak developing in the vacuum casing, only helium can enter the vacuum system.

The special arrangement of the triple-containment of the cryogenerators is described in para. 4.1.

2. THE SUPERCRITICAL SYSTEM

As mentioned in para. 1.2. the system is supercritical, i.e. the hydrogen pressure - 15 bar abs. - is above critical pressure which is about 13 bar abs.

In the temperature-entropy chart for normal-hydrogen, which is shown as fig. 2, it can be seen that hydrogen of 15 bar abs. always would be in a single phase. As the temperature range during operation will be 28-40°K, and the pressure is the abovementioned 15 bar abs., it may be seen from the T-S chart that the density will be about 63 g/l-12 g/l.

The supercritical system offers some advantages over other systems, as no phase change takes place and as the density of the hydrogen may be changed by changing the temperature, which can be used for optimizing the neutron gain.

All cold neutron sources with hydrogen moderators built until now have been based on use of liquid hydrogen. In ref. 1 the supercritical system is proposed in the design study of the cold source for the Harwell High Flux Beam Reactor. In that study the system was proposed to operate in the temperature range 33-38°K, which would give a reduced hydrogen density compared with liquid hydrogen density. This reduction was intentional and based on geometrical considerations.

3. IN-PILE SECTION

A feature of the system for DR 3 is the possibility of getting two cold neutron beams, one from each end of the horizontal beam hole 7TL3.

The in-pile section for the 7TLF·3 end contains the moderator chamber and was designed to have a helium cooled neutron filter.

A beam-plug is placed in the opposite end of the horizontal beam hole. The cold neutrons passing through this plug are split into two beams, one to a spectrometer at the reactor face, and the other beam is led out to a neutron physics house outside the reactor building by means of a neutron guide tube.

The neutron spectrum emitted from the moderator chamber, contains the full thermal spectrum plus the enhanced tail of cold neutrons. If cooled neutron filters are used most of the thermal neutrons, a proportion of the fast neutrons and many of the gamma rays are filtred out, while the cold neutrons are transmitted. This effect is caused by a very sharp drop in neutron scattering cross section of beryllium, at 80°K σ = 6b for E_n > 6 meV and σ = 0.005b for E_n < 6 meV, at 300°K σ = 0.5b for E_n < 6 meV.
This would say that the filters are virtually opaque to thermal neutrons, but transparent to cold neutrons.

At present no internal neutron filters are used as they are not necessary from a biological point of view and external filters are used when necessary.

3.1. Plug with Moderator Chamber

This plug is shown in fig. 3. The moderator chamber, made of aluminium alloy AlMg3, is placed inside the vacuum casing, which is made of the same aluminium alloy. The vacuum casing is jointed to the shield plug head in order to avoid seals in the radiation field. This joint is made with an indium wire seal. The hydrogen pipes are run in grooves in the top of the shield plug. Thus it is possible to mount the moderator chamber and the pipes as a unit. As the hydrogen pipes are connected to the transfer line with stainless steel couplings, transition joints have been used between the aluminium pipes and the stainless steel coupling parts. These joints are of a well proven friction welded type and they are placed about 175 mm from the couplings. The hydrogen pipes are supported by helical springs and the moderator chamber is centred by three spacers in the vacuum casing. The moderator and heat transfer circuit is described in para 4.2.

The γ-heating in the vacuum casing is removed by a flow of D_2O through a coil of omega shaped tube wound around the casing, see papa. 4.9.

The originally used neutron filter insert was cooled by a flow of cold helium from the intermediate stages of the cryogenerators, see para. 4.5. The helium flow passed around the filter blocks in a spiralled groove. This cooling jacket was insulated by a vacuum annulus, which was connected to the vacuum in the rest of the plug and in the hydrogen transfer line. This vacuum system is named Vacuum I, see para. 4.7. The vacuum insulation of the cold helium transfer line was separated from the vacuum in the plug by bellows, a helium layer, and a further bellows around each of the two pipes. At present the neutron filter insert and the helium transfer line are removed as argumented above.

The shield plug tip is cooled by a water flow through a coil in the lead shielding.

4. OUT-PILE EQUIPMENT

The layout of the total system is shown in fig. 4.

The two cryogenerators are placed on the "moveable" deck at reactor face 1, just above the beam hole. The cryogenerators are connected to the system through the joint box. The cryogenic fans and valves are all placed in this box. The moderator chamber is connected to the joint box by a transfer line. Earlier the cooling jacket for the neutron filters was as well connected to the joint box by a transfer line.

Two separate vacuum pump units are placed underneath the joint box. One unit is used to evacuate the plug and the transfer line, and the other is used to evacuate the rest of the vacuum insulation. In order to protect the vacuum containment against overpressure in case of a burst on the helium or the hydrogen pipes, both the in-pile vacuum and the out-pile vacuum are provided with relief valves, which relieve the pressure to the atmosphere outside the reactor shell through a helium chamber in the relief box.

The hydrogen buffer and supply system is placed outside the reactor shell. The standby cooling of the moderator chamber is connected to the hydrogen supply system.

In the following paragraphs a description of the different systems is given.

4.1. Philips-Stirling Cryogenerators

The cold neutron source is refrigerated by two Philips-Stirling four cylinder, two-stage cryogenerators. This type of cryogenerator contionuously performs a modified Philips-Stirling cycle, which may conveniently be described in terms of four distinct phases.

A quantity of helium gas, at room temperature and high pressure, is compressed in the compression space (1) by the upward movement of the working piston (P) see fig. 5. The initial downward movement of the displacer (D) then transports most of the compression-heated gas through the water cooler (2), first regenerator (R1) and exchanger (4) to the intermediate expansion space (3). At the same time, part of the gas passes through the second regenerator (R2) and top cold-exchanger (6) to the top expansion space (5). Thus cooled to two different "working" temperatures, the helium in both expansion spaces expands as displacer and working piston descend together, and absorbs heat through the cold-exchangers (4 and 6). The return of the displacer channels the gas back through the regenerators (R1 and R2), where heat stored from the compression phase is efficiently taken up again, and the helium arrives back in the compression space restored to its initial state. In practice, the phases of compression, cooling, expansion, and regeneration are merged into a continuous cycle.

Two heat-exchanger coils are brazed to the top- and intermediate cold-exchangers on each cylinder. The gas passing through these coils is cooled to between approximately 14 and 30^{o}K (H_2) and 60 and 80^{o}K (He). These coils form parts of the two separate, closed gas transfer circuits described in the following paragraphs.

The temperatures of the top cold-exchangers are measured by means of germanium resistance thermometres.

On the top stages of the cylinders heating cables are brazed for testing and controlling the cold output of the cryogenerators.

The cold part of the generator is placed inside a vacuum-chamber. This vacuum-chamber is surrounded by a helium blanket, except for the 25 mm thick stainless steel bottomplate. The germanium restistance thermometer and the heating coil feed-throughs in the bottomplate are, however, made in such a way that the helium blanket is retained locally.

The cylinder head feed-throughs in the bottomplate, which are sealed with O-rings, are covered by a local nitrogen blanket at 1.3 bar abs. as helium would give too much diffusion through the O-rings which are needed to allow for the tolerances of the machines.

4.2. Hydrogen Moderator and Heat Transfer Circuit

Hydrogen at 15 bar abs. is circulated between the moderator chamber and the top cold-exchangers of the Philips-Stirling cryogenerators by one of the two fans, H-B11 or H-B12. Under normal operation one of the cryogenerators and one of the fans are in operation, originally two operating cryogenerators was considered necessary for proper cooling. The other fan is stand-by and the changeover is initiated by a rise in the temperature H-TIT 35 of the moderator chamber. The fans are driven by means of two separate 200 Hz power supplies, H-B11 on supply 1 and H-B12 on supply 2.

The hydrogen circulation through the cryogenerators may be stopped by closing either the valves H-Ve2 or H-Ve4 or both. The hydrogen circulation through the fans H-B11 and H-B12 may be stopped by closing the valves H-Ve1 and H-Ve3 respectively. These valves and fans are located in the joint box.

The hydrogen temperature is measured both at the inlet and outlet of each generator by sensors H-TI1 to H-TI4, and in the common pipes by sensors H-TI9 and H-TIC10. These sensors are germanium resistance thermometers.

4.3. Hydrogen Buffer and Supply System

The purpose of this system is to keep the hydrogen pressure within the operational range during temperature changes and to provide the system with clean hydrogen.

This system is placed outside the reactor shell in a light aluminium house except for the buffer vessel, which is placed in the open air. The buffer vessel has a volume of 4.0 m^3. This volume is big enough to prevent the pressure falling below the critical pressure and thus prevents the formation of two phase hydrogen. Furthermore, pressures above 17 bar abs. are avoided when the system is at ambient temperature. The buffer vessel is isolated from the system if the pressure H-PAT 30 falls below 14 bar abs. by closing the valves H-Ve27 and H-Ve28.

An orifice of 4 mm is placed between the buffer and the system in order to restrict the hydrogen flow in the event of a failure of the hydrogen system.

The system is filled with high purity hydrogen, i.e. hydrogen with a purity better than 99.99%. Even though high purity hydrogen is used, it is passed through a nitrogen cooled molecular sieve filter, before it is fed into the system.

After the connection of a new gas bottle, the pipes between the bottles and the valve H-Ve33 is pumped down to a vacuum better than 0.1 Torr by means of the vacuum pump H-Vp5, filled with hydrogen and blown down again.

The vacuum pump H-Vp5 is also used to evacuate the whole hydrogen system before filling.

The vacuum pump H-Vp 5 is purged with nitrogen when it is stopped.

If the system pressure exceeds 18.2 bar abs., the pressure-control system activates the valve H-Ve24 and if that fails, the relief valve H-Ve23 opens at a pressure of 18.8 bar abs.

The hydrogen is relieved through a chimney through which the exhaust from the vacuum pump H-Vp5 is also conducted.

4.4. Hydrogen Standby Cooling Circuit

This cooling circuit is started by the control system, whenever the reactor is operating and neither of the cryogenerators is in operation, to prevent overheating of the moderator chamber and pipes in-pile.

The standby circuit is initiated by the thermocouples H-TIT 13, 14 and 15 on the moderator chamber. When the standby circuit is needed, the control system opens the valve H-Ve25, closes the valves H-Ve2 and H-Ve4 and starts the fan H-B15, which operates in series with the already parallel operating fans H-B11 and H-B12. The fan H-B15 is driven by means of a third 200 Hz power supply.

4.5. Cooling of the Originally used Neutron Filter

The helium flow through the intermediate cold-exchangers of the cryogenerators was used to cool the neutron filter. The helium pressure was 20 bar abs.

The helium was circulated between the neutron filter and the cryogenerators by one of the two fans, He-B13 and He-B14. The other fans was started if the temperature He-TIT 19 or 20 exceeded 90°K.

He-B13 and He-B14 were driven by the same 200 Hz power supplies as the fans H-B11 and H-B12, i.e. He-B13 on supply 1 and He-B14 on supply 2. The helium circulation through the cryogenerators could be stopped by closing the valves He-Ve6 or He-Ve8 or both. The helium circulation through the fans He-B13 and 4 could be stopped by closing the valves He-Ve5 and He-Ve7 respectively. These valves and fans were located in the joint box.

The helium was circulated between the filter and the cryogenerators in a vacuum insulated transfer line (Vacuum III). The helium temperature was measured at the inlet and outlet of each generator with germanium resistance thermometers, He-TI5-8.

4.6. Helium Buffer and Supply System

A common supply system is used for both the originally used neutron filter cooling system, the working gas for the cryogenerators and for the helium blanket system. Later when the He-cooling circuit was removed the He-buffer was also removed, and the He-supply for blanket and cryogenerators were separated.

The helium is cleaned by a liquid nitrogen cooled molecular sieve filter before it is fed into the system.

The buffer vessel for the neutron filter cooling system had a volume of 0.3 m^3. This volume was big enough to limit the pressure variation when the system was cooled down. The helium system was provided with a pressure control system. He-PAT24 gave a warning at 19 bar abs. and isolated the buffer vessel at 18 bar abs. by closing the valve He-Ve47. He-PAT36 gave a warning at 22 bar abs. and opened the valve He-Ve49 at 26 bar abs. A relief valve He-Ve48 ensured that the pressure could not exceed 29 bar abs.

The blanket system, which operates at 1.3 bar abs. is supplied through a reducing valve He-Ve54.

4.7. Vacuum Systems

As mentioned in para. 1.3. all hydrogen containing equipment inside the reactor shell are contained within high-vacuum systems. For the cold equipment the vacuum also acts as the insulation.

The vacuum surrounding the moderator chamber, the pipes in the in-pile section and the pipes in the hydrogen transfer line comprise one vacuum system, named Vacuum I, The vacuum in the vacuum chambers of the cryogenerators and in the joint box is named Vacuum II, and the vacuum in the helium transfer line is named Vacuum III.

Vacuum I is established by means of the turbo-molecular vacuum pump Val-Vp2, backed by the rotary pump Va-Vp1.

Vacuum II and III are established by means of the turbo-molecular vacuum pump VaII-Vp4, backed by the rotary pump VaII-Vp3.

The vacuum is established before start up of the experiment and sealed off by the valves VaI-Ve13, VaII-Ve20 and VaIII-Ve21 respectively.

The valves HeI-Ve61 and VaI-Ve67 are then opened and helium is admitted to the pipe line in order to complete the triple containment.

During operation, when Vacuum I and II are sealed off, the vacuum is kept below 10^{-6} Torr by means of ion-pumps, Vp7 on Vacuum I and Vp8 on Vacuum II, and cryopumping onto the cold surfaces.

The ion-pumps Vp7 and Vp8 have pumping speeds for helium at 9 l/s and 18 l/s respectively. These pumping speeds limit the maximum helium leaks to approximately 10^{-5} Torr l/sec and 2×10^{-5} Torr l/sec in order to keep pressures below 10^{-6} Torr and thereby the pump lifetime higher than 2 years.

Vacuum I and II is monitored by triple Pirani gauges in each vacuum PIT1-3 and PIT8-10. These gauges give a warning in a 1-out-of-3 connection at 5×10^{-3} Torr, and change from the cryogenerators to the standby cooling in a 2-out-of-3 connection at 5×10^{-2} Torr (see section 5). Three switches on each of the vacuum systems I and II, PT4-6 and PT11-14 trip the reactor in a 2-out-of-3 connection at 0.2 bar abs. and depressurises the hydrogen pipe lines after isolating the buffer volume.

The vacuum is divided in two separate systems, chiefly to facilitate finding a possible leak, but it has also the advantage that it is only necessary to break Vacuum II to service the cryogenerators and the components in the joint box. Both vacuums are provided with a Penning gauge (10^{-2} - 10^{-6} Torr) P17 and PI14. These gauges are used to measure the operational vacuum in the two systems together with the total pressure facilities of the ion pumps.

The ion pumps Vp7 and Vp8 are automatically switched off at 1×10^{-4} Torr.

Both Vacuum I and II are protected against overpressure by the relief valves VaI-Ve14 and VaII-Ve15. These relief valves blow to a helium volume - Helium III - which is provided with two relief valves in parallel, Ve62a and 62b. In this way the triple containment philosophy is also kept around the relief valves VaI-Ve14 and VaII-Ve15.

Vacuum III is monitored by two Pirani gauges, PIA15 and 16, and provided with a relief valve, Ve66.

If the ion-pump VaII-Vp 8 can not keep Vacuum II below 10^{-6} Torr the turbo-molecular vacuum pump VaII-Vp 4, backed by the rotary pump VaII-Vp 3, may be started as long as the vacuum can be kept below $5x10^{-2}$ Torr at which level the valve VaII-Ve 20 will be closed by VaII-PIT 8, 9, 10 in a 2-out-of-3 connection. (See section 5.)

4.8. Helium Blanket Systems

As the safety philosophy is based on the triple-containment principle, all pipe lines and equipment containing hydrogen inside the reactor shell are contained within a vacuum containment, which again is surrounded by a helium blanket.

For the same reasons as mentioned in para. 4.7, namely leak finding and the necessity only to break a part of the system when components are serviced, the helium blanket is divided in two systems connected by the valve HeI-Ve59, which is open during operation. Helium I covers Vacuum I and Helium II covers Vacuum II. The Helium is always at a small positive pressure, say 1.3 bar abs., so the helium pressure will decrease if there is a leak in the helium containment. A decrease gives a warning in a 1-out-of-3 connection at 1.2 bar abs., and trips the reactor in a 2-out-of-3 connection at 1.1 bar abs. followed by a depressurisation of the hydrogen system. The three pressure switches on Helium I, HeI-PAT20 to 22, are common for the two helium systems, as the two systems are connected during operation. Each of the systems is provided with a manometer HeI-PI19 and HeII-PI23.

HeI is protected against overpressure by the relief valve HeI-Ve58 which blows at 1.35 bar abs.

The helium blanket around the relief valves VaI-Ve14 and VaII-Ve15 on the vacuum systems is a separate system, Helium III, connected to Helium I by the valve HeI-Ve60, which is closed during operation. Helium III is provided with three pressure switches HeIII-PAT26-28 and a manometer, HeIII-PI25.

The helium blanket systems are connected to the common helium supply system through a reducing valve He-Ve54 adjusted to 1.33 bar abs.

4.9. D_2O-Cooling of Vacuum Case

The γ-heat from the aluminium vacuum case must be removed to maintain strength.

The vacuum case is cooled by a flow of D_2O in a coil of omega shaped tube wound around the vacuum case.

D_2O rather than H_2O is used since this will not depress fluxes to the same extent. Ref. 2 mentions that the flux depression with H_2O would be 13% worse than with D_2O.

In order to avoid a special D_2O circuit, with all the complexity that would add to the system, the vacuum case is cooled by a flow of D_2O from the reactor circuit.

The cooling coil is connected between the level and ion exchange circuit of the reactor and the storage vessel 1V3/2.

The D_2O flow (100 l/h) and temperature are measured, D_2O-FI1, TI30 and 31.

The plug for the other end of the beam hole, 7TLA·3 is provided with a D_2O leak detector D_2O-TIA32 near the bottom of the liner to give a warning if D_2O should leak into the liner (HeI).

5. SAFETY ASSESSMENT

The safety philosophy is based on triple containment which was explained in para. 1.3. By adopting this philosophy both the potential explosion hazard arising from irradiated solid air, and the more conventional hydrogen/oxygen explosion hazard, when a source of ignition is present, are precluded.

If one of the triple containments is lost the intrumentation automatically trips the reactor and depressurises the hydrogen system.

The only reasons for vacuum deteriorations are either helium leaks or hydrogen leaks. Neither presents a hazard, but as neither hydrogen nor helium will cryopump, the vacuum deterioarates and the thermal insulation is not sufficient at a pressure of about 5 x 10^{-3} Torr. The pressure in the two vacuum systems is monitored by triple Pirani gauges in each system, giving a warning in a 1-out-of-3 connection at 5 x 10^{-3} Torr and change from the cryogenerators to the standby cooling in a 2-out-of-3 connection at 5 x 10^{-2} Torr. Three pressure switches in each vacuum trip the reactor in a 2-out-of-3 connection at 0.3 bar abs. and depressurises the hydrogen system.

During normal operation Vacuum II can alternatively be pumped by the turbo-molecular vacuum pump VaII-Vp4 (70 l/sec), backed by the rotary pump VaII-Vp3, if the ion-pump VaII-Vp8 can not keep Vacuum II below 10^{-6} Torr. As the valve VaII-Ve20 will be closed at 5 x 10^{-2} Torr by PIT 8, 9, 10 in a 2-out-of-3 connection the maximum continuous release of hydrogen to the DR 3 containment will be $\sim$0.5 mg/sec, which will cause no hazard. A sudden release of hydrogen in Vacuum II will as well cause a closing of the valve

VaII-Ve20 but as the closing time is about 2-3 seconds some hydrogen may be released to the containment through the vacuum pumps. The release from a double-ended pipe fracture would give a calculated release in the order of $\sim$3.6g corresponding to $\sim$13 l/sec. before the valve VaII-Ve20 is closed.

Experimental releases of helium in the order of $\sim$133 l/sec (8Nm^3 in total) have given no concentration above 0.9% (vol.).The abovementioned release of hydrogen in the order of $\sim$13 l/sec should therefore not exceed the ignition limit of 4% except at the release point which is above normal working level.

If the helium pressure in the blanket system decreases, there will be no hazards as long as the pressure is above ambient. Three pressure switches in common for Helium I and II and three pressure switches on Helium III, is giving a warning in a 1-out-of-3 connection at 1.2 bar abs. and trip of the reactor in a 2-out-of-3 connection at 1.1 bar abs. followed by a depressurising of the hydrogen system.

If nitrogen, from the local nitrogen blanket around the cylinder head feed-throughs in the bottomplates of the cryogenerators, is leaking into Vacuun II there will be no hazards.The nitrogen will cryopump and therefore cause no pressure increase. A leakage of 0,2g - to Vacuum II and/or to the surrroundings - will give a warning at 1.2 bar abs. in the nitrogen system.

The pressure in the vacuum systems in the event of failures on the hydrogen system has been calculated. The maximum credible accident in Vacuum I is a total fracture of the moderator chamber.

Under conservative assumptions the maximum pressure in the vacuum casing is calculated to 4.5 kp/cm^2 abs. Even if one of the relief valves (HeIII-Ve62a or 62b) fail simultaneously and the heat transfer is assumed to be a factor of 3 higher, the pressure will not exceed 14.5 kp/cm^2 abs. This pressure will not cause any damage to the vacuum system (VaI).

The maximum credible accident in Vacuum II is a fracture of a hydrogen tube. It has been calculated that the vacuum containment will remain intact in this event.

A failure of the helium cooling jacket round the filter will not be as serious as a hydrogen failure since the heat transfer conditions cause a smaller expansion of the gas.

When the cold source is filled with hydrogen the crane must not be allowed to carry any load above the area occupied by the equipment.

6. MEASUREMENTS OF THE NEUTRON FLUX FROM THE COLD SOURCE

Just shortly after start up of the cold neutron source the spectrum of the neutron flux was determined (ref.3.).

Figure 6 shows the ratio of the flux observed at the sample for the 28K H_2-source and the flux observed previously for the ~350K water source. The measurements were performed under otherwise identical circumstances except for changes caused by the refueling of the reactor. Such variations are normally less than 10%. The ratio represents the true gain produced by the installation of the cold source. It is remarkable that the gain at 5 meV is more than an order of magnitude and that there is a gain of more than two in the frequently used energy range around 15 meV; the gain is 1 around 20 meV.

The cold source is operated in the supercritical region at a pressure of approx. 15 bar atm. This means that the effective thickness of the source changes quickly with the source temperature. The corresponding effect on the flux at the sample is shown on Fig. 7. It is obvious that the effect is quite small for temeperatures less that 40K, which means that the spectrum is comfortably independent of the operation of the cold source.

The actual spectrum in absolute units is shown in Fig. 8 for the 1. order component. The comparison with the water scatterer spectrum shows that the energy of the flux maximum has been shifted considerably towards lower energies. This means that the higher order contamination is a much smaller problem in beams from the cold source. To illustrate this effect we have determined the ratio of second to first order monitor counts in a fission monitor in the monochromatic beam, shown in Fig 9. This ration passes 1 around 15 meV for a normal thermal neutron beam.

The conclusion from these measurements of the cold source performance is the following: The cold source beams are ideally suited for a large fraction of the current inelastic neutron scattering studies. The tremendous gain at the lowest energies have made a range of high resolution experiments practical, and it has made the DR 3 reactor comparable to a high flux reactor as a neutron source in this range.

7. EXPERIENCE OF OPERATION

7.1. Normal Operation of the Cold Source

The operation of the cold source closely follows the operation of the reactor because of the necessity to cool the moderator chamber during reactor operation.

The reactor is operating 23 days at a time followed by a 5 days shut down.

The cold source is started and cooled down some hours before the reactor is started and stopped and warmed up some hours after the reactor is shut down. The warm up takes approximately 12 hours.

This close connection to the reactor operation have the great disadvantage, that all major repair and maintenance is restricted to 4 days in each reactor shut down, where the work load on the reactor crew - who also operate the cold source - is already high. This also means, that the reliability of the cold source is of major concern.

Every 4 hours all important operating parameters, such as temperatures, pressures etc, are logged and compared to nominal operating values in order to be able to make proper corrections before any break down or automatic shut down of the cold source.

Further any repair or maintenance operation to be made during shut down is carefully planned at least a week before shut down.

7.2. Achieved Operating Parameters of the Cold Source

The obtained neutron gain has been discussed in section 6.

The spectrometer counting time for a specific number of counts has been measured in dependance of the hydrogen temperature, H-T10, at a neutron energy of 4.6 and 5 meV. The result was, that below 36.5 K the counting time was constant. Above 36.5 K the counting time is increasing after an S- curve. At 38 K the counting time is increased with 45%, at 40 K with 86% and at 45 K with 152%.

Philips recommends the working gas presssure in the cryogenerators not to exceed 29 bar. In order to achieve a better lifetime especially of the regenerators the working gas pressure is kept at 23-24 bar.

In table 1 is shown typical achieved operating parameters.

Table 1, typical operating parameters

	2 cryogener. operating		1 cryogener. operating	
	a	b	a	b
Hydrogen temperature H-T10 [K]	26-28	32-33	35-36	38-40
Working gas pressure [bar]	23-24			
Hydrogen pressure [bar]	15-16			
Presssure Vac I [m bar]	10^{-6}-10^{-8}			
Pressure Vac II [m bar]	10^{-6}-10^{-8}			
Temperature of He-circ. [K]	60-70			

a. Recently regenerated or new regenerators.

b. Oil contaminated regenerators before regeneration (still in acceptable condition).

It is seen, that it is possible to operate the cold source with only minor losses in neutron flux until shortly before regeneration is needed with only one cryogenerator operating. As this gives considerable savings in costs and manpower this has been done as the main mode of operation.

7.3. Cold He-Loop

At the time of start of operation of the cold source the He-cooled bismuth filter was installed. As filters were not necessary from a biological point of view the filters and the cold helium loop have later been removed.

7.4. Regenerators

During operation both the phosphor-bronce gauze regenerators of the high temperature stages and the leadball regenerators of the low temperature stages of the cryogenerators are contaminated with oil, which reduces the efficiency of the regenerators. It is therefore necessary regularly to clean the regenerators from oil in order to maintain a good cooling capacity of the cryogenerators.

Originally cleaning intervals of 4000 hours was agreed with Philips, but in practice it has not been possible to exceed 3000 hours. Normally the regenerators are cleaned every 2500 hours.

The cleaning is performed with petroleum ether, and it is controlled, that the regenerators regain their original weight after cleaning.

Due to the necessary disassembly, reassembly and testing the regeneration is the most time consuming of a number of maintenance works to be carried out.

An unexpected and expensive experience achieved is, that the lifetime of the lead regenerators is only approximately 7000 hours. These regenerators are very expensive (Approx. 20.000 Dkr/piece $\sim$ 6300 DM/piece), and the shift to new regenerators is very time consuming.

7.5. Major Problems of Operation

Problems with regenerators have already been discussed in section 7.4.

A number of other problems with the cryogenerators have occured.

Both cryogenerators have been completely overhauled including insert of new principal bearings.

Several repairs of the crank shaft feed-through oil seal have been necessary.

Cleaning of displacers at the same time as the regenerators have prooved necessary.

Leaks on the cryogenerator vacuum casing has caused trouble, and the casing has been modified.

Problems with the oilpump in one cryogenerator have occured.

Problems have occured by not observing operation instructions concerning cleaning of working gas for the cryogenerators. The supply system for blanket gas and working gas has therefore been partly separated together with the removal of the cold He-system.

Of other problems could be mentioned:

Insert of new ball bearings in the fast running hydrogen- (and earlier also helium) blowers has been necessary very often due to the infavorable operating conditions. This work requires carefull alignment of the blower shaft.

Leaks from H_2- or He-pipes to the vacuum system have occured now and then, but much more frequently there have been problems with leaks from the He-blanket to the vacuum system. Such leaks are troublesome because it takes time - even with a He-mass spectrometer-detector - to locate and repair them, and there is only 4 days to do the job in the shut down period. It has therefore often been necessary to pump continuously on Vac II with the turbo-molecular pump VaII-Vp4 during normal operation.

Though a lot of operational problems have occured it has nevertheless been possible to keep a very high availability for the cold source as seen in table 2.

Table 2. Availability for Cold Source during Reactor Operation

Year	avaliability %				
	cryogen. no. 1	cryogen. no. 2	cryogen. no. 1 or 2	cryogen. no. 1 and 2	acceptable neutron flux obtained
1975	91	91	100	82	100
1976	67	75	83	58	83
1977	100	85	100	85	92
1978	100	86	100	86	85

7.6. Manpower and Expences for Maintenance and Repair

At normal operation the annual operating expences are approximately as follows:

New regenerators,	75000 D.kr/year
Other spare parts for cryogenerators,	10000 D.kr/year
Electricity,	65000 D.kr/year
Other,	10000 D.kr/year
Total annual expences,	160000 D.kr/year

Annual Manpower at Normal Operation:

Cleaning of regenerators snd displacers,	32 man days/year
Shift to new regenerators,	13 man days/year
Other maintenance,	120 man days/year
Total annual manpower,	165 man days/year

Two things should be pointed out 1) when the cold source and the cryogenerators get older the manpower and the expences are expected to increase considerable, 2) major special events, e.g. complete overhaul of cryogenerators, are not included above.

After some more years annual expences and manpower of 200000 D.kr/year and 200 man days/year therefore seem to be realistic estimates.

Due to the relatively high annual expences and manpower and the expected increasing problems by maintaining the cryogenerators, (this cryogenerator model is no longer manufactured) installation of a new turbo-cooling system in some years is under consideration.

8. EXTENSION OF FACILITY

8.1. Possibilities for Extension to Two Cold Sources

As discussed in section 7.2. the cooling capacity for the existing cold source is so large, that normally only one of the two cryogenerators are operating.

As one additional cold source cooled by the same cooling system would only increase the needed cooling capacity with approximately 60%, there would be more that enough cooling capacity for operating two cold sources with two cryogenerators.

8.2. Lay Out for Potential Two Cold Source System

The lay out for a potential two cold source system is shown in figur 10.

The inpile part for the second cold source is placed in the horizontal experimental hole 7TLA1 at the same reactorface as the first cold source.

During normal operation the hydrogen flow will go from the joint box to a new hydrogenliner, where it separates into two parallel flows - one to each cold source - and are united again after leaving the inpile parts and returns to the joint box and the cryogenerators.

In case of break down or repair of one of the cryogenerators the cooling capacity is too low for two cold sources with the remaining cryogenerator. By placing the valves H-Ve105, H-Ve115 and 116 in the right positions, it should be possible to cool the existing cold source as today from the remaining cryogenerator, and at the same time cool the new cold source to below 100^{o}C by an external loop via the blowers H-B15 and 6 and a water cooler. This external cooling is provided via a new hydrogen liner.

As before the inpile parts of the two cold sources can be standby cooled.

In the diagram it is seen, that the cold He-loop is removed, and that the supply of blanket-He and working gas-He is to some extent separated in order to ease the daily work with the systems.

8.3. Status and Prospects

The status is:

The cold He loop is removed and the inpile part of the cold source modified appropriately. The He supply to blanket and cryogenerators are separated. Two new hydrogen liners are manufactured and installed. The inpile part of a potential cold source no. 2 is manufactured, see figur 11. Necessary electric work and installation of additional instrumentation has been performed.

The remaining things to be done in achieving two operating cold sources are modification of the valves H-Ve115 and 116 and installation of the inpile part for cold source no. 2.

Decision whether a second cold source should be installed has been postponed at least to the autumn 1981. This have several reasons:

- Some technical difficulties have appeared. These are however partly solved now.

- The manpower and costs by keeping two cryogenerators in proper operation is causing increasing worry. This should therefore be investigated closely until autumn 1981.

- The need of the Physics Department for a second cold source has to be reviewed.

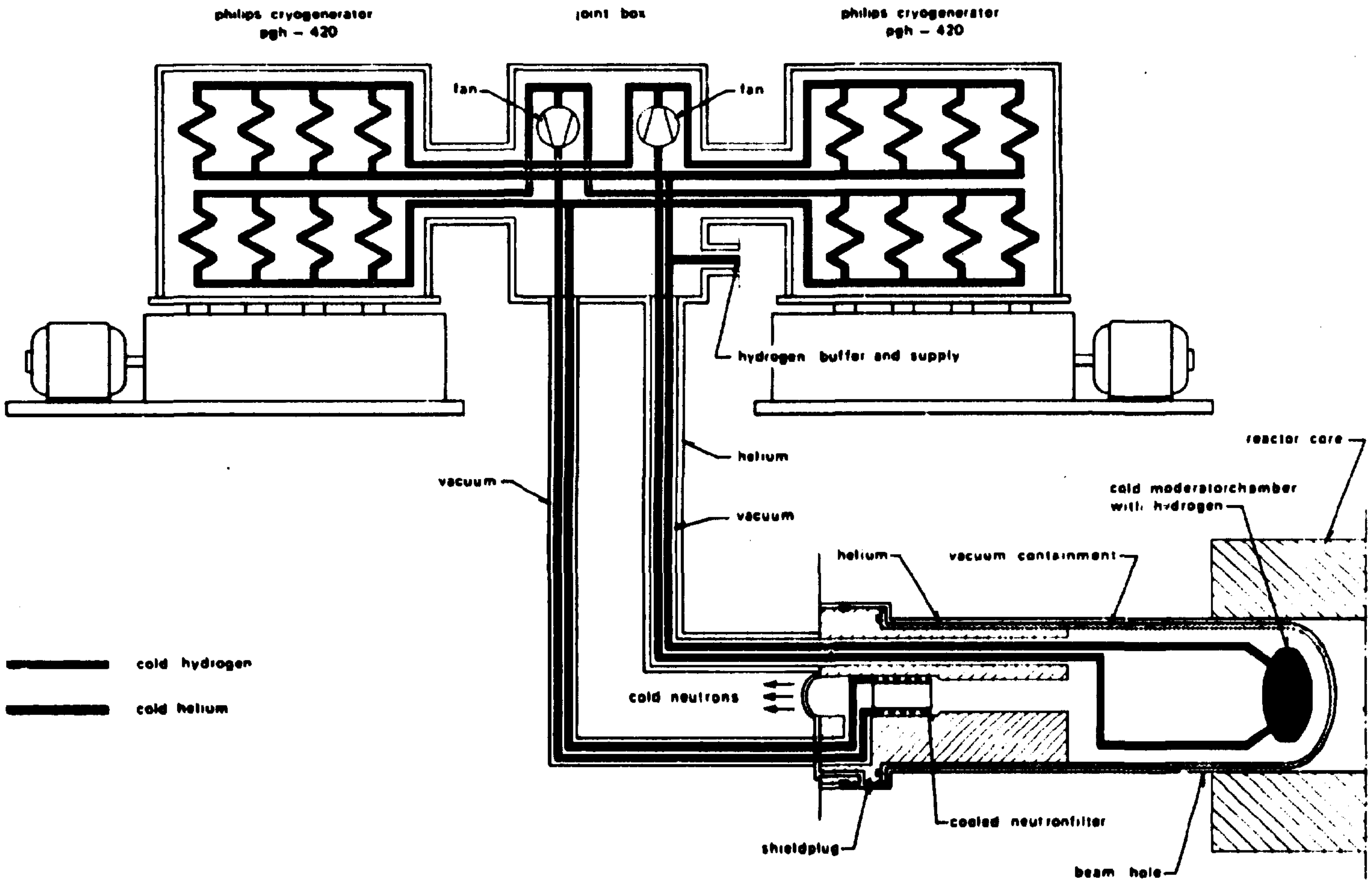
- Installation of a new turbocooling system instead of the cryogenerators has to be investigated together with the possibility to buy a new cryogenerator and build a cryogenerator test stand.

9. REFERENCES

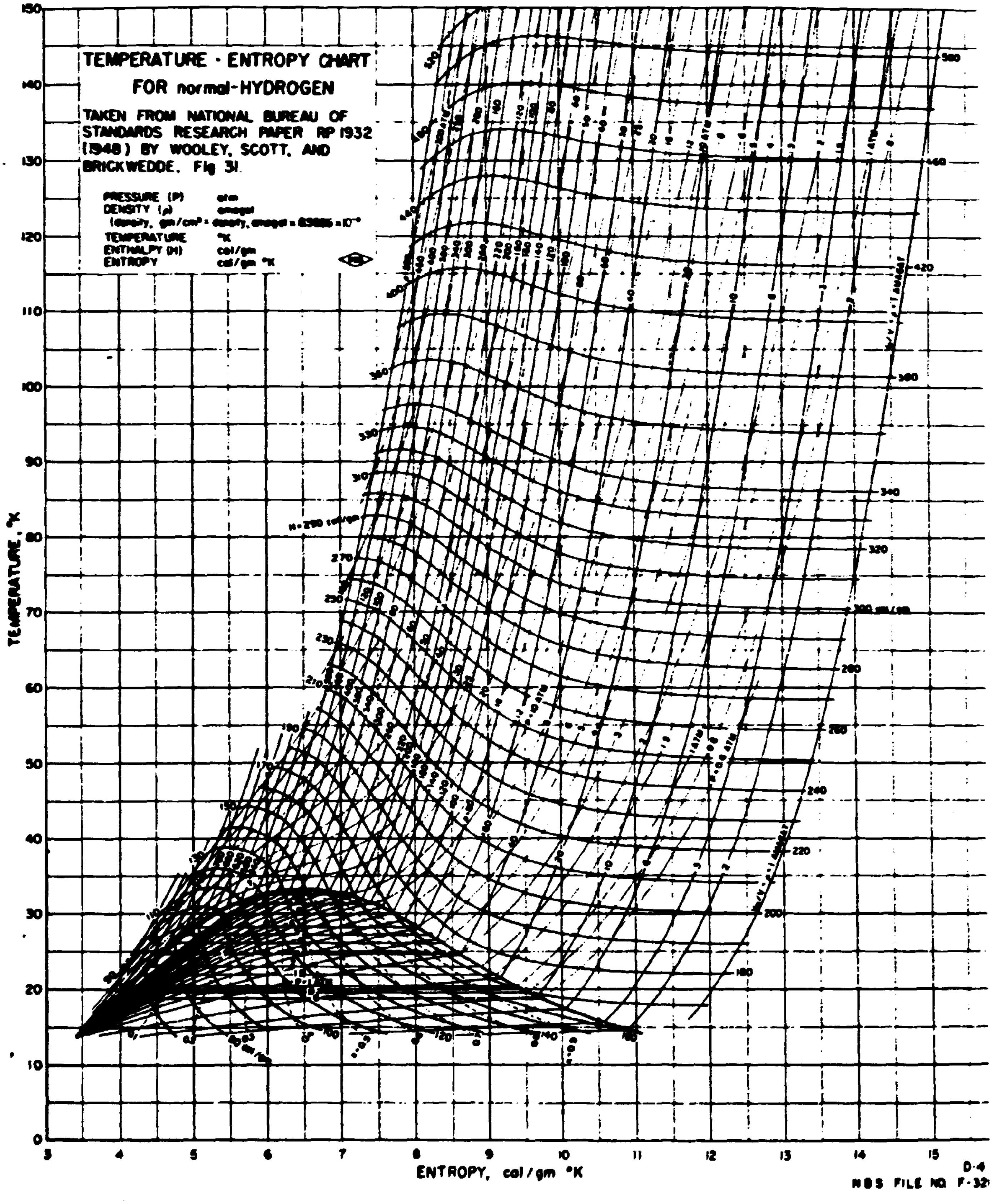
Ref. 1. D.G. Pearce,
"A Design Study of the Cold Source for the Harwell High-Flux Beam Reactor". AERE-R 5752, 1968.

Ref. 2. D.J. Merrett, D.G. Pearce and F.J. Webb,
"Design of a Liquid Hydrogen Cold Neutron Source for the 6th Hole in DIDO".

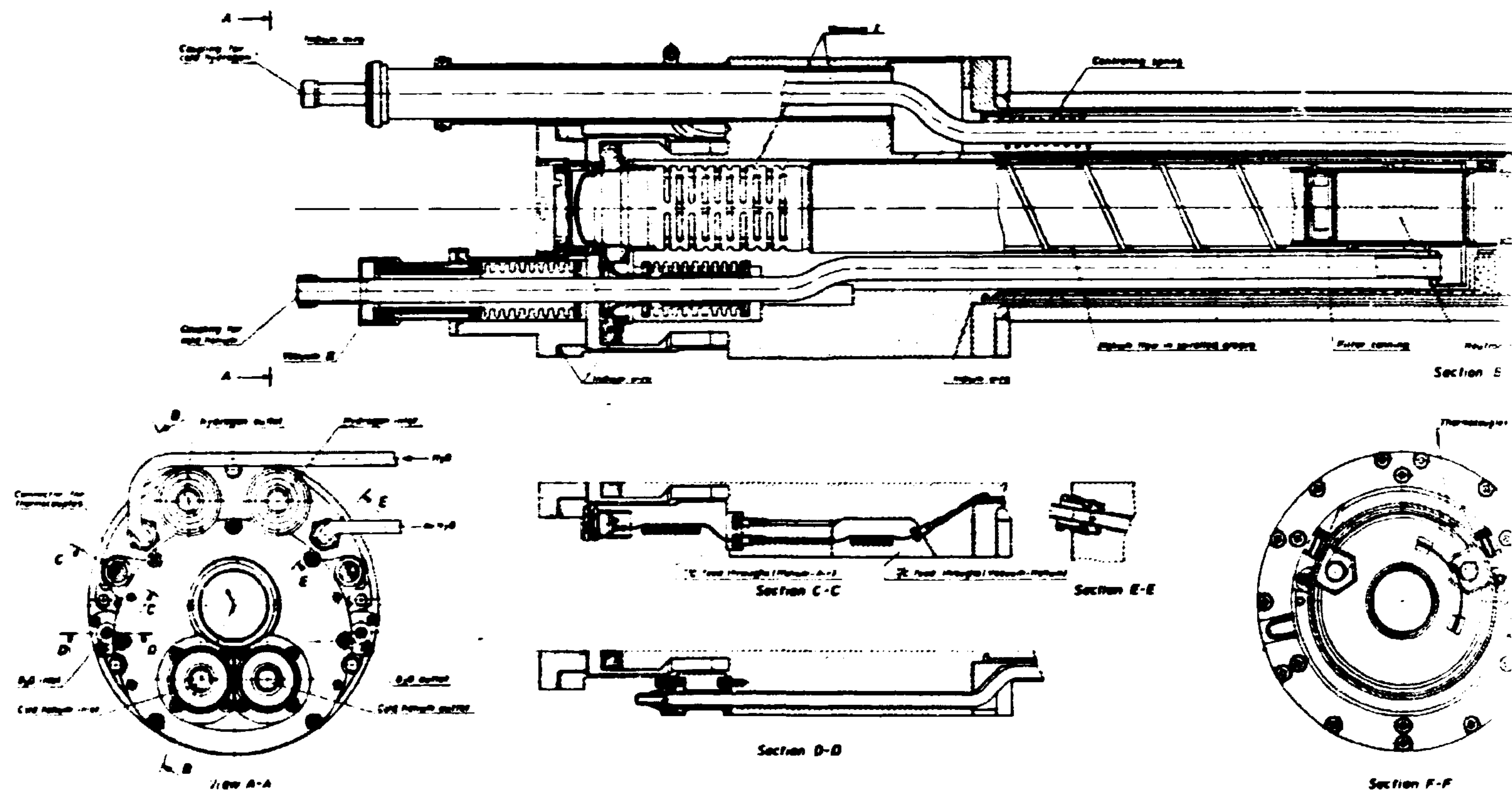
Ref 3. J. Als Nielsen and J.K. Kjems,
"Measurements of the Flux from the Cold Source at DR 3, Risø M 1802, May 1975".



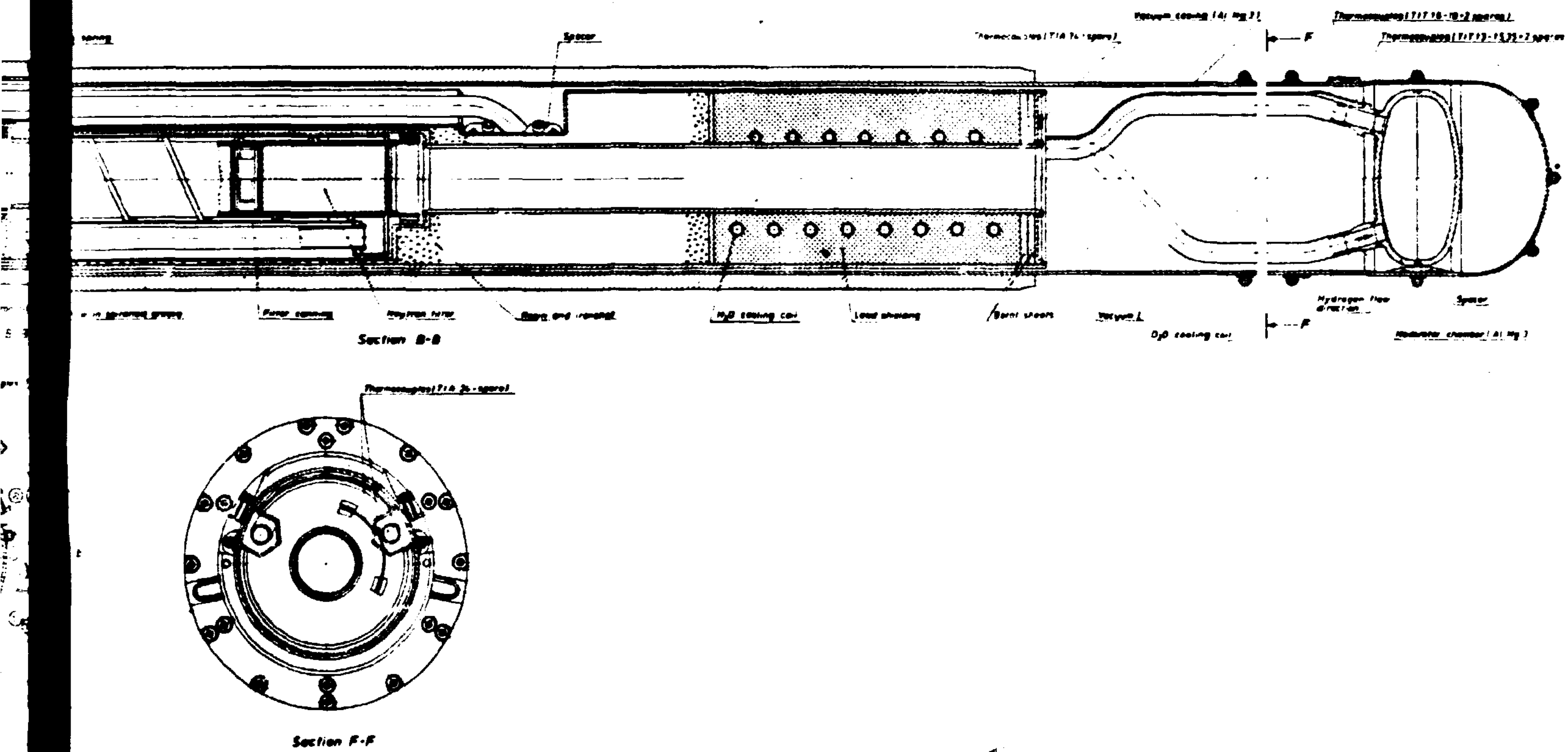
Figur 1. Schematic layout of the cold neutron source



Figur 2. Temperature- entropy chart for normal hydrogen

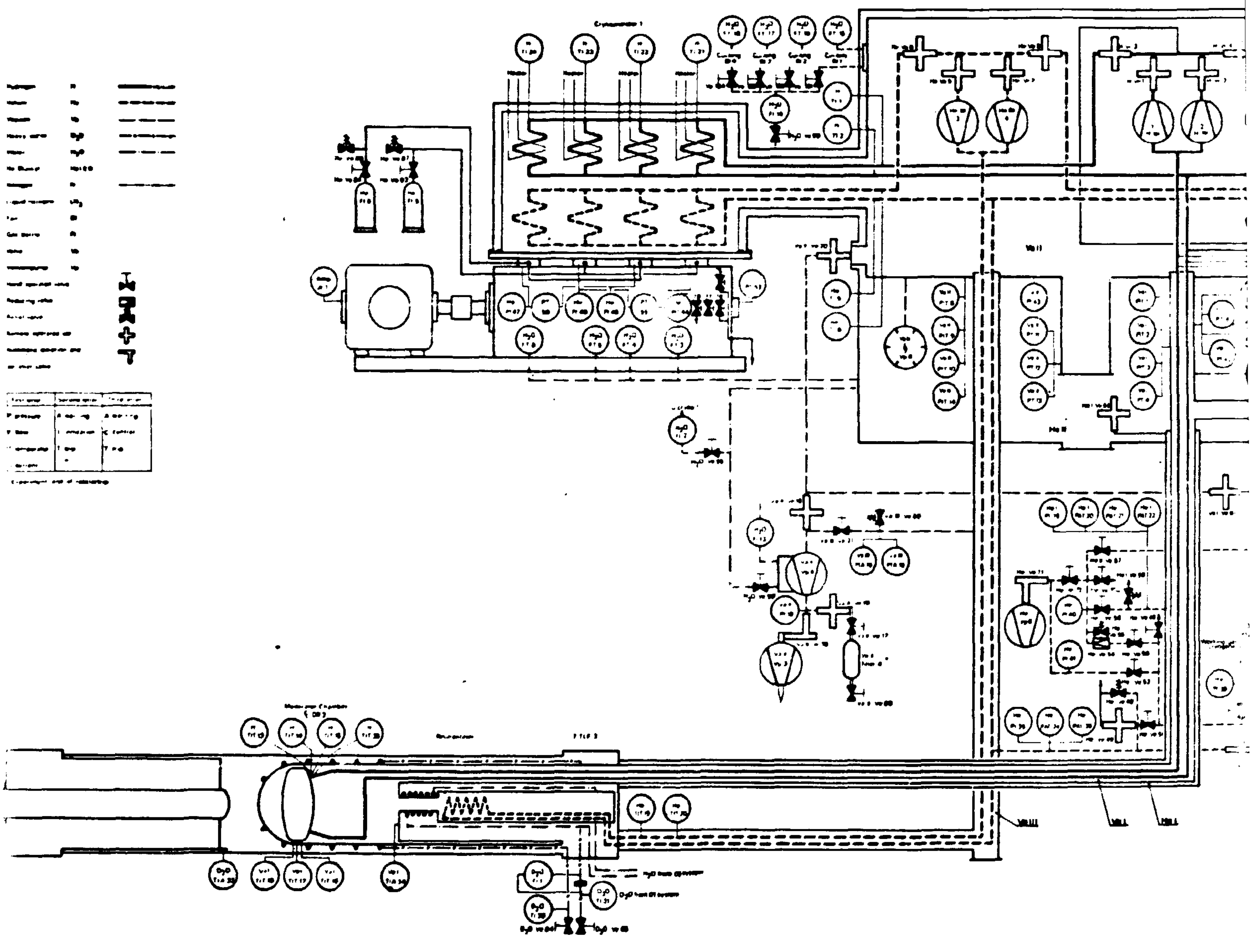


SECTION 1

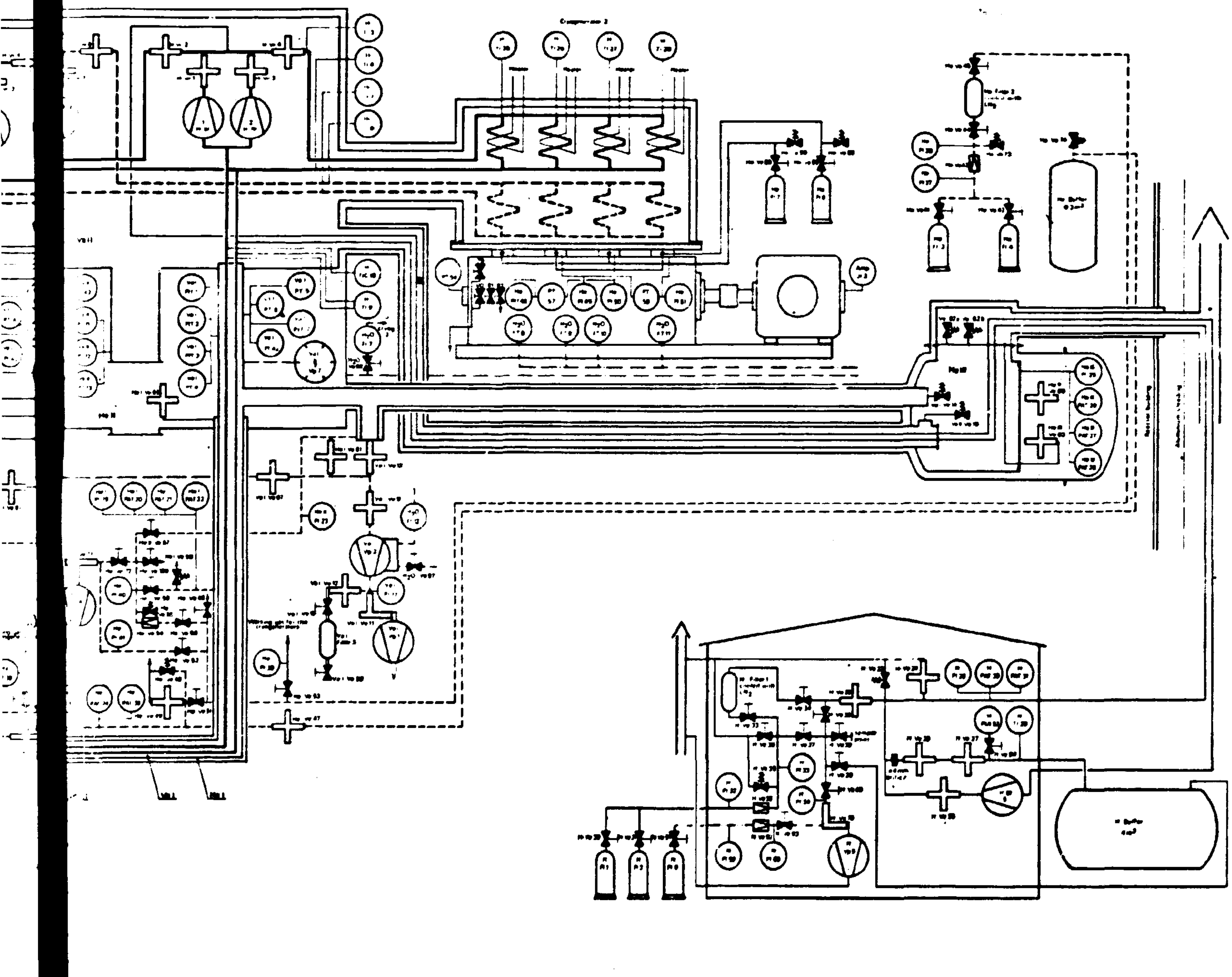


SECTION 2

Figur 3. In-pile section with moderator chamber

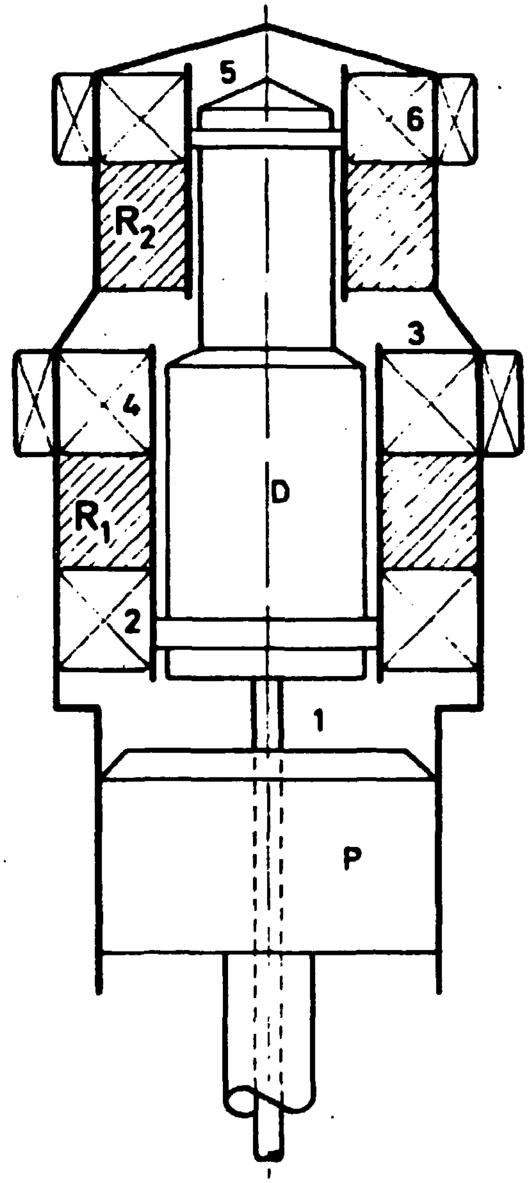


SECTION 1

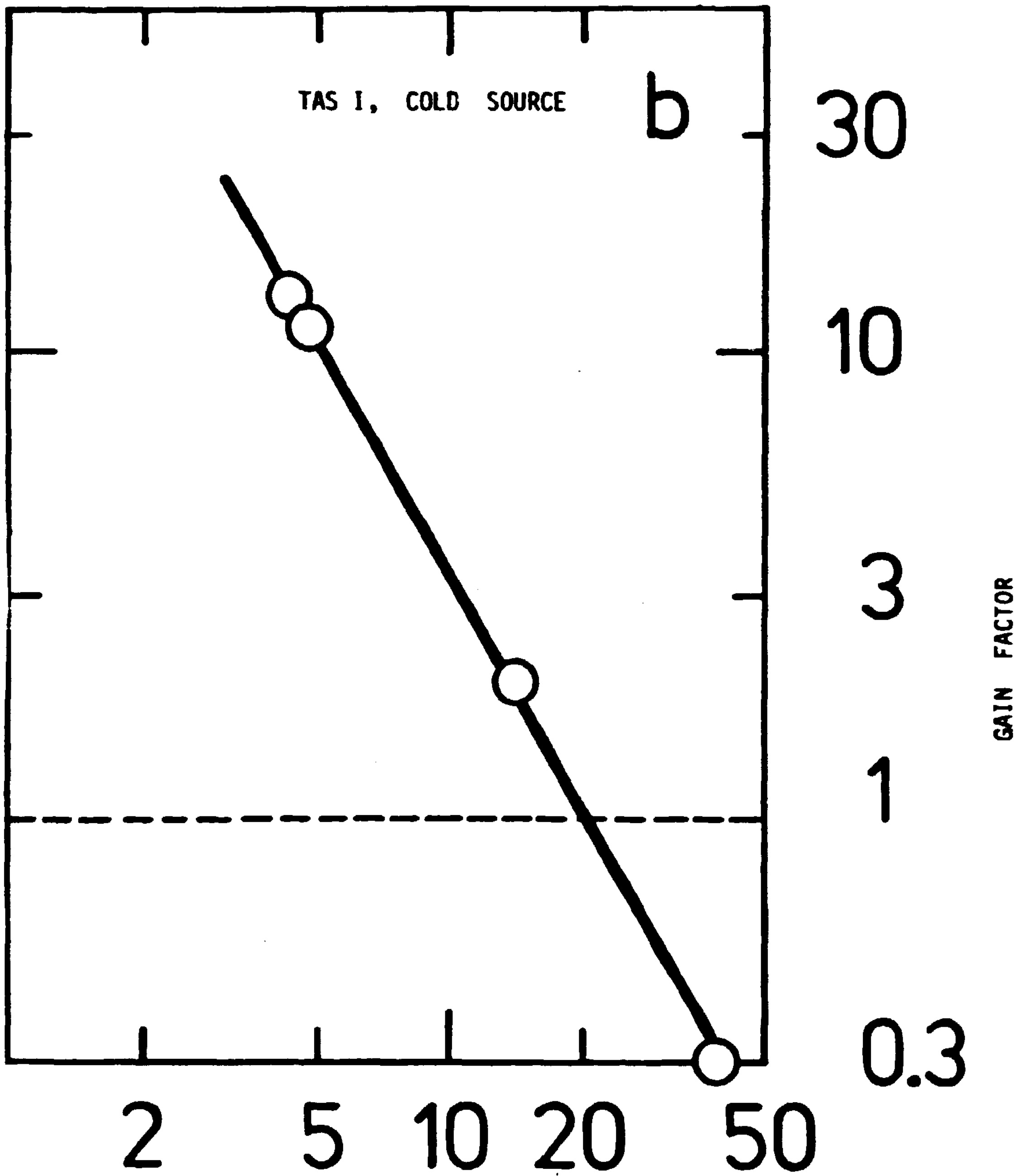


Figur 4. Layout of the cold neutron source

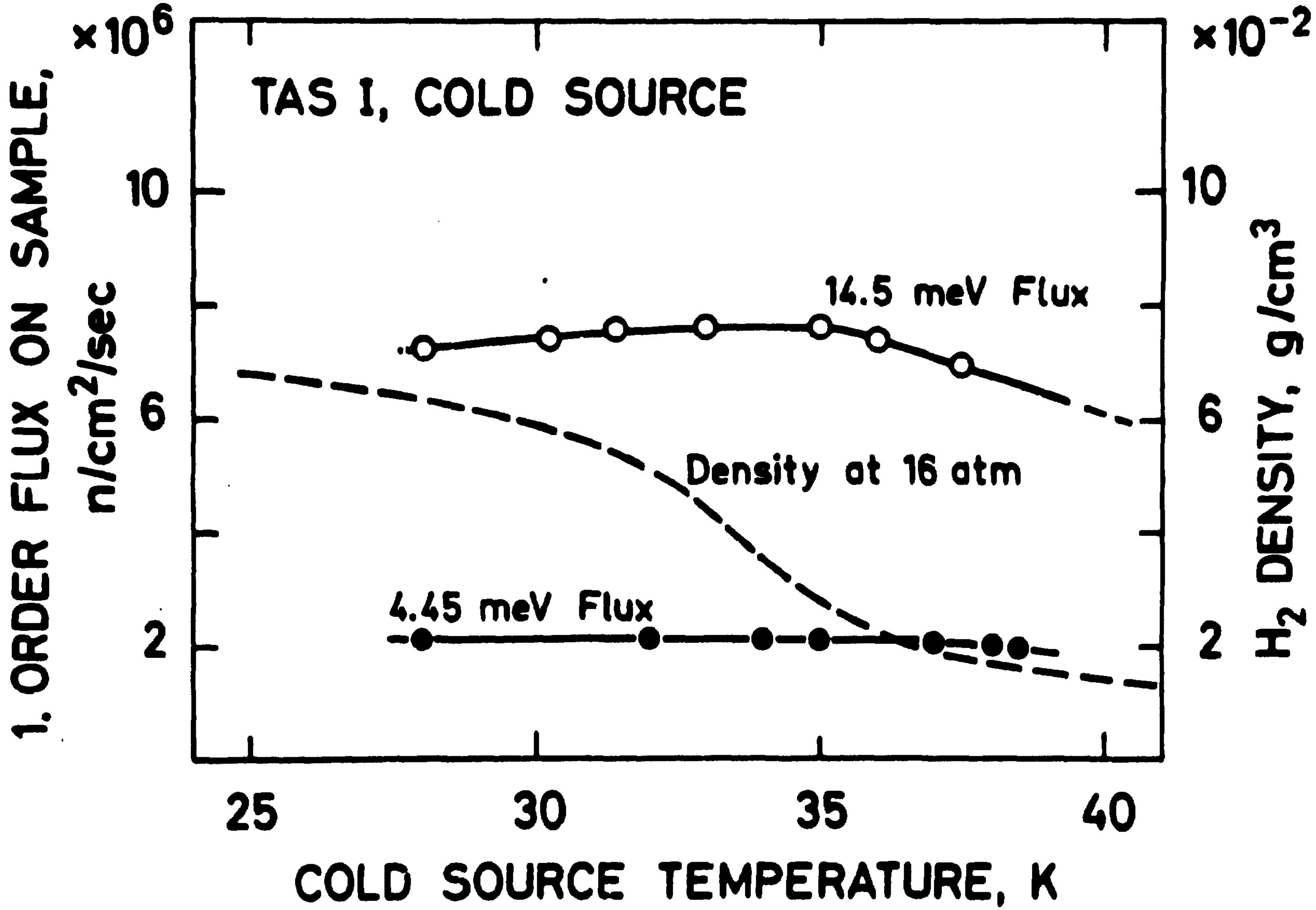
SECTION 2



Figur 5. Philips-Stirling cryogenerator

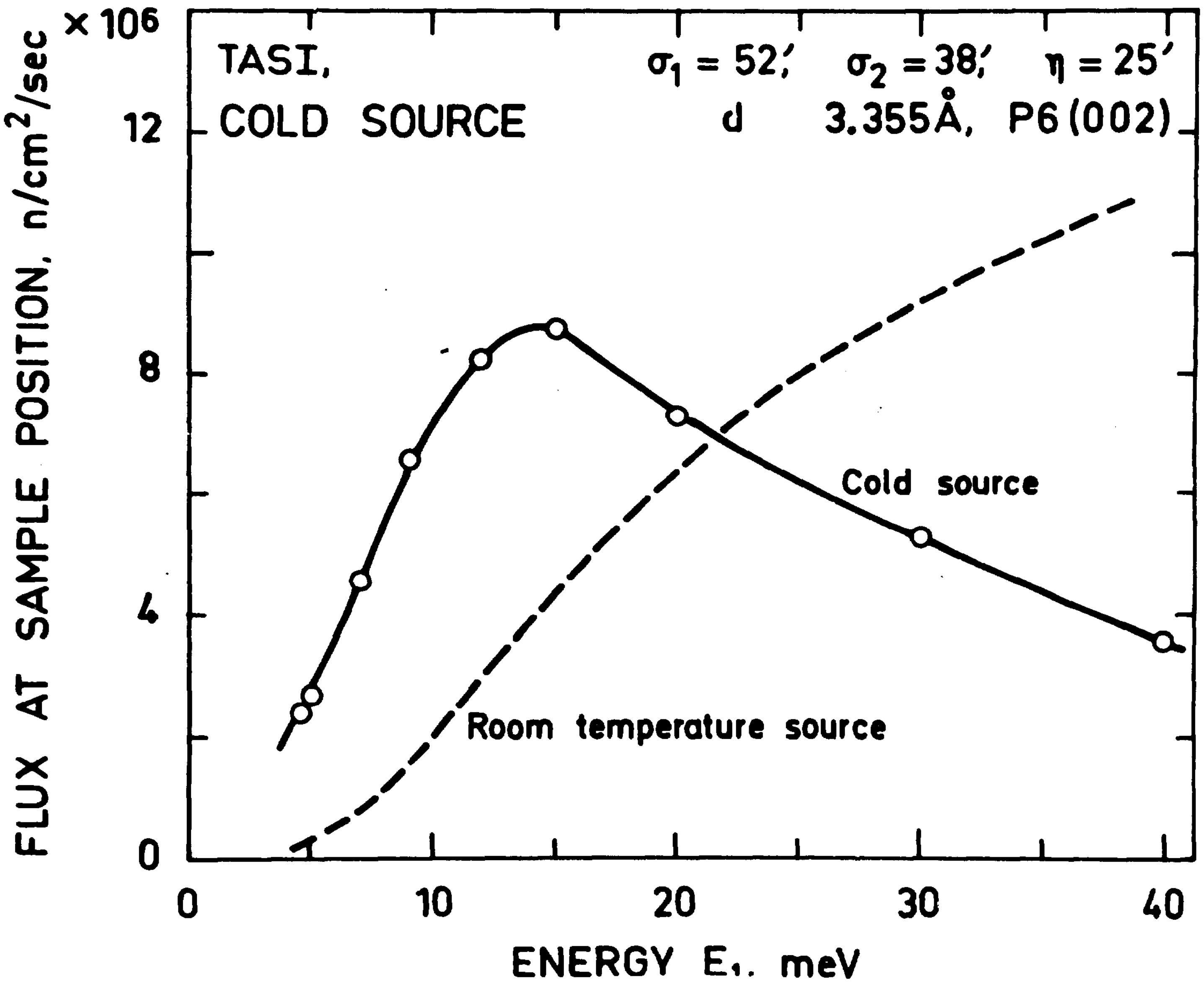

TAS I, COLD SOURCE
b
30
10
3
1
0.3
GAIN FACTOR
2
5
10
20
50
NEUTRON ENERGY, meV

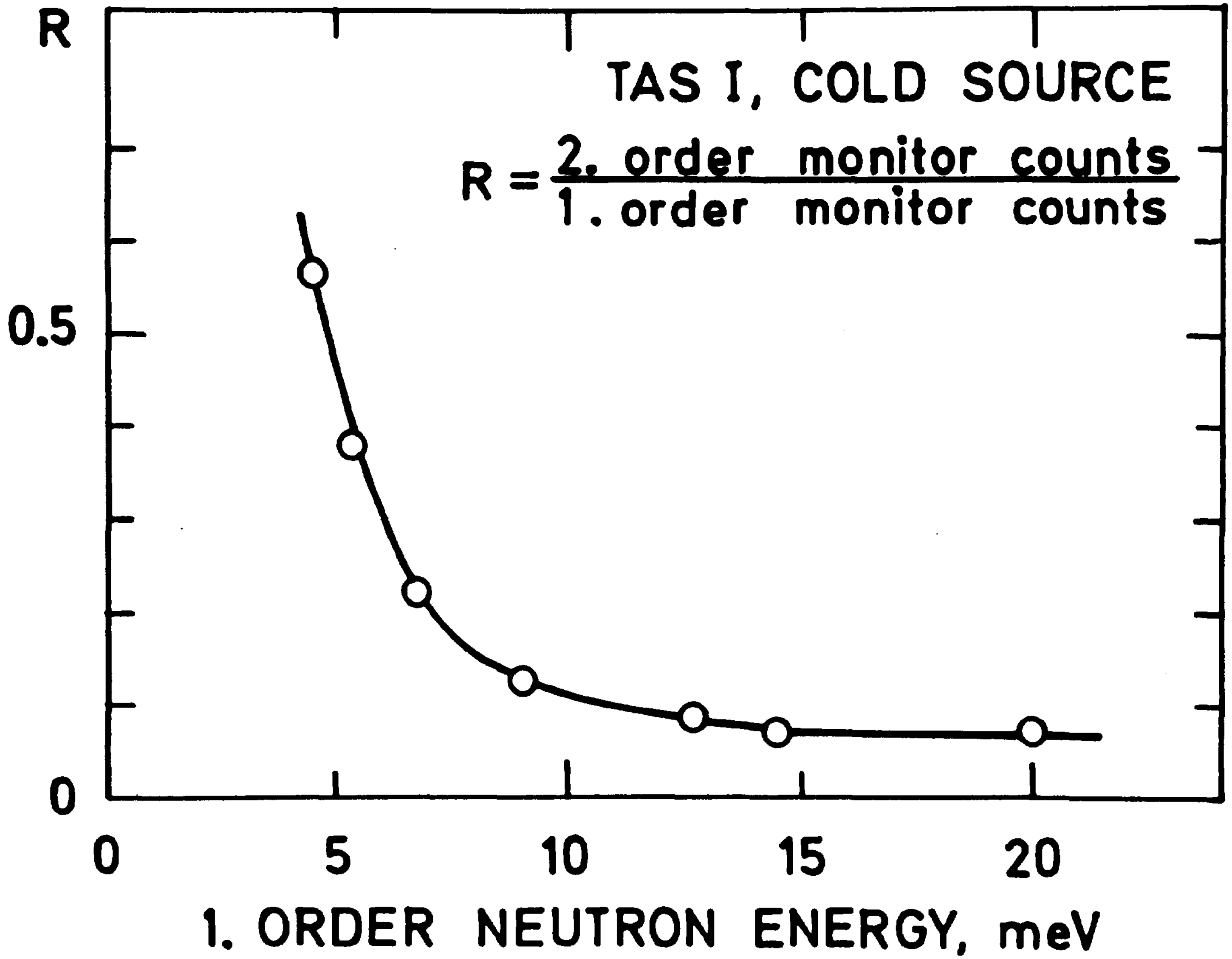
Figur. 6


TAS I, COLD SOURCE
14.5 meV Flux
Density at 16 atm
4.45 meV Flux
1. ORDER FLUX ON SAMPLE, n/cm²/sec
×10⁶
H₂ DENSITY, g/cm³
×10⁻²
10
6
2
25
30
35
40
COLD SOURCE TEMPERATURE, K

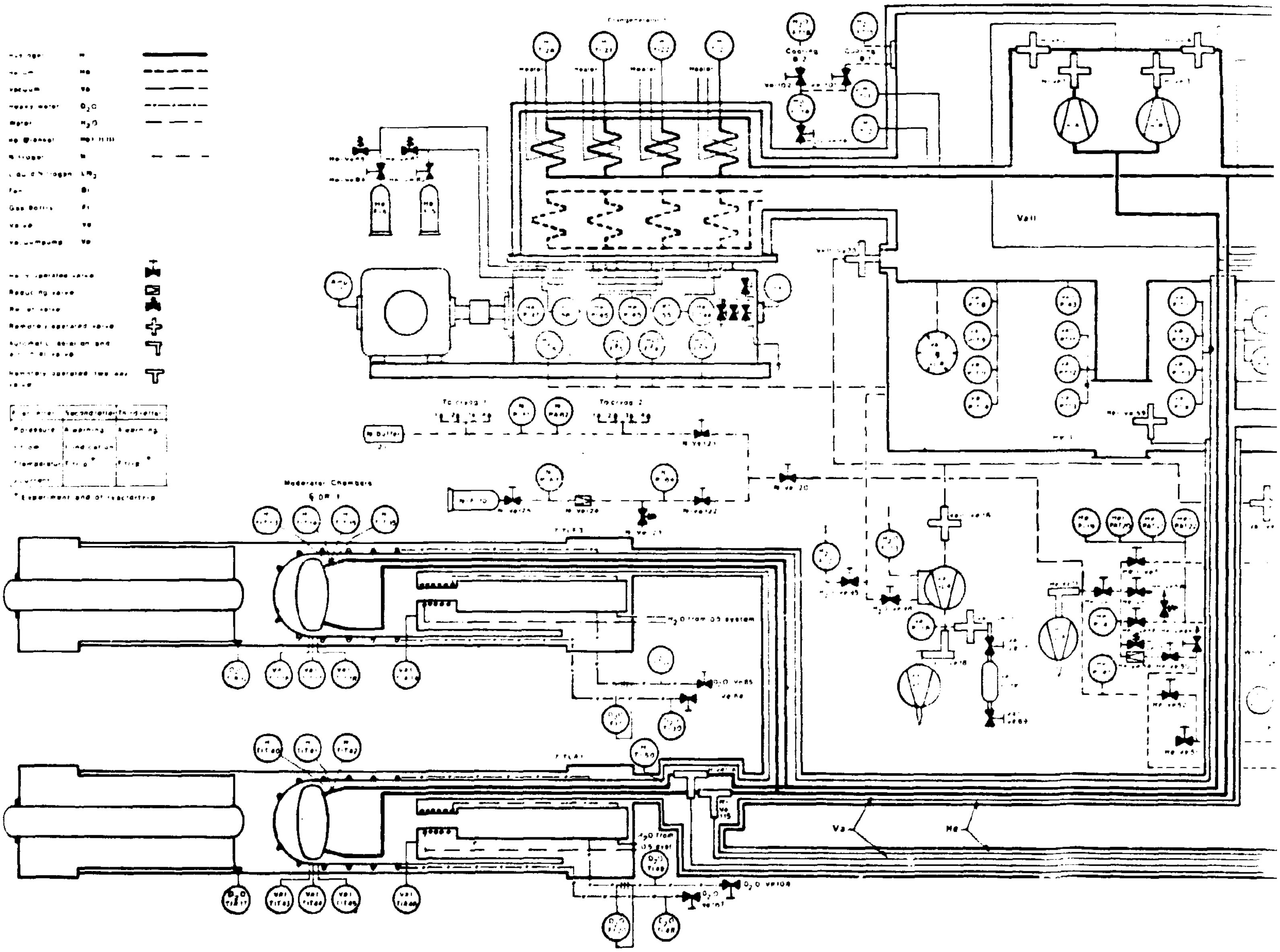
Figur 7

Figur 8

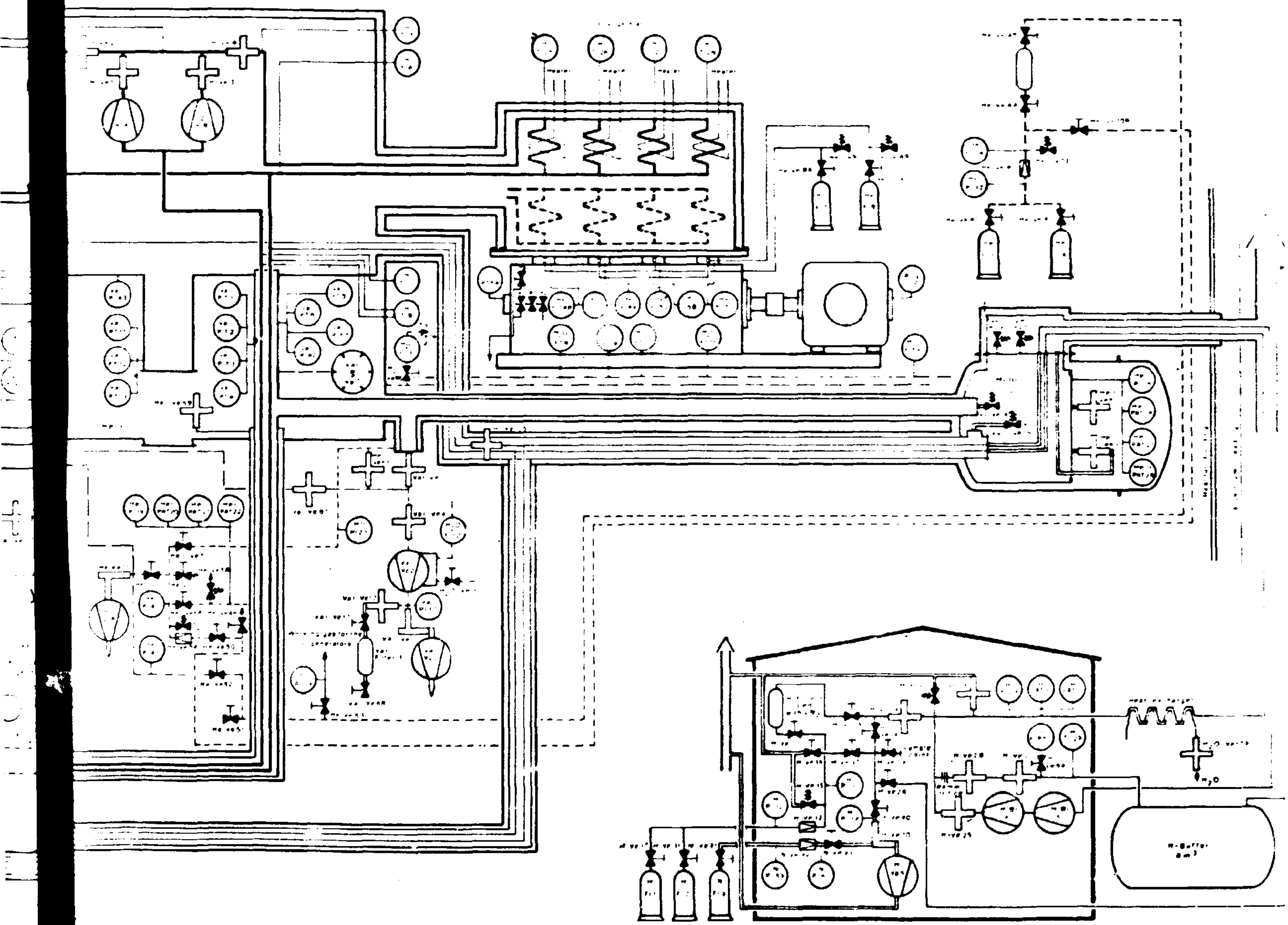

TASI,
COLD SOURCE
$\sigma_1 = 52'$ $\sigma_2 = 38'$ $\eta = 25'$
d 3.355Å, P6(002)
Cold source
Room temperature source
FLUX AT SAMPLE POSITION, n/cm²/sec
× 10⁶
0
4
8
12
0
10
20
30
40
ENERGY E₁, meV


R
TAS I, COLD SOURCE
R = 2. order monitor counts / 1. order monitor counts
0.5
0
0
5
10
15
20
1. ORDER NEUTRON ENERGY, meV

Figur 9

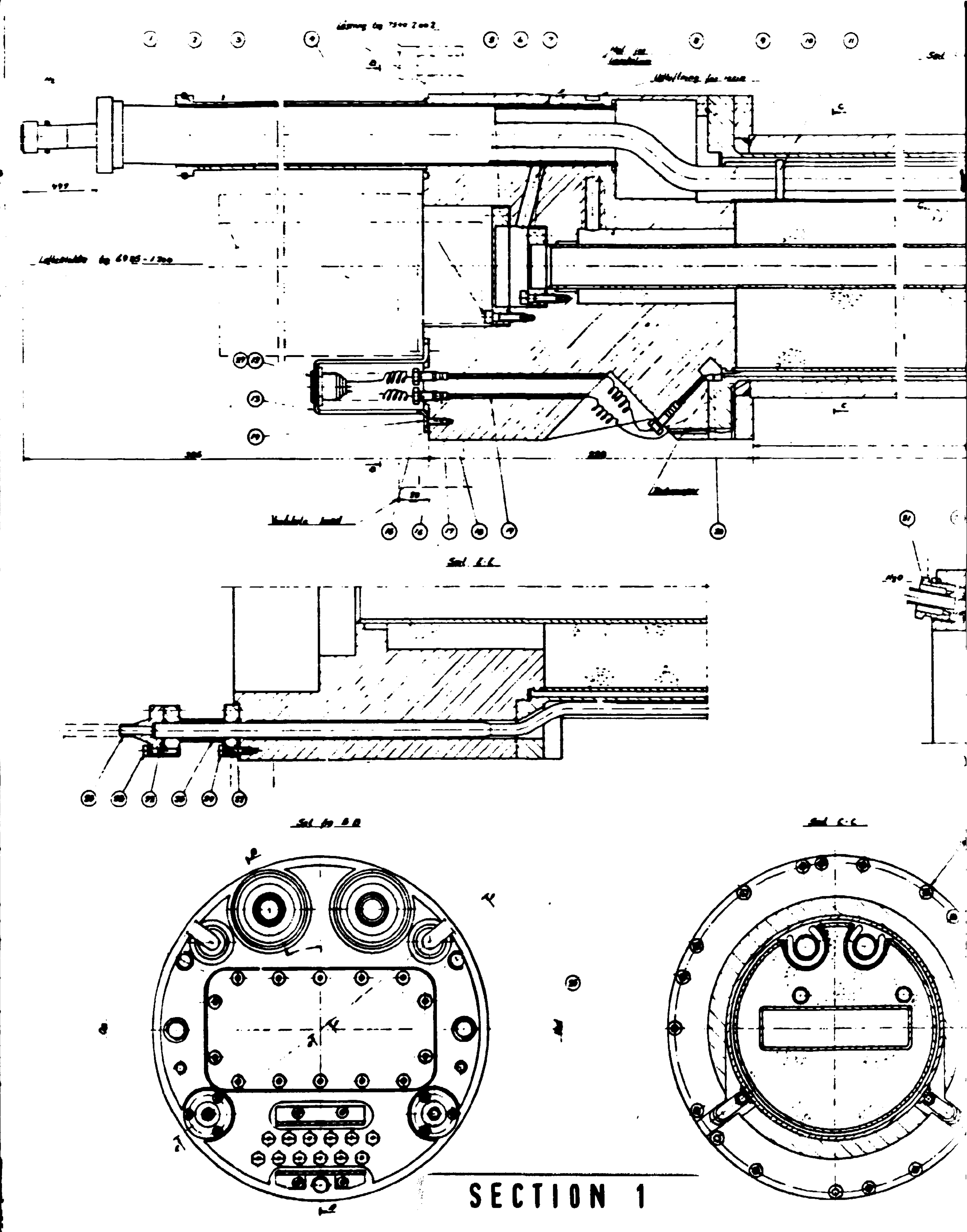


SECTION 1

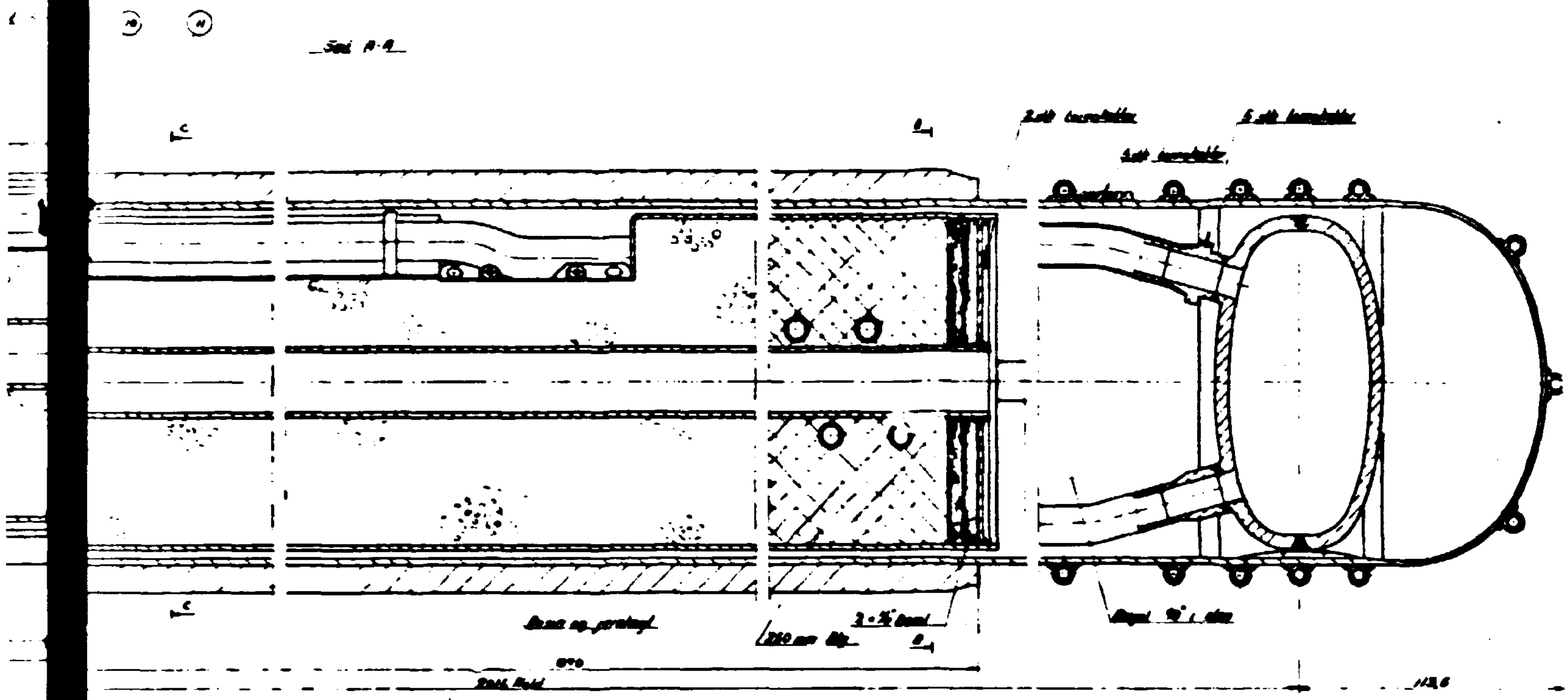


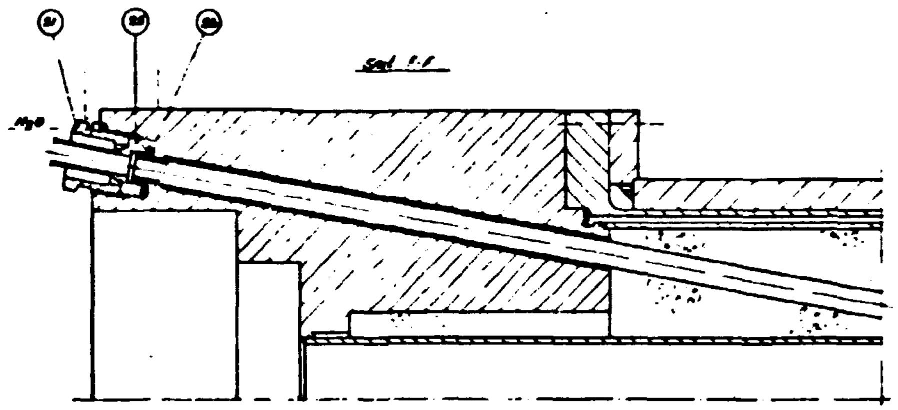
Figur 10, Layout of two cold neutron sources

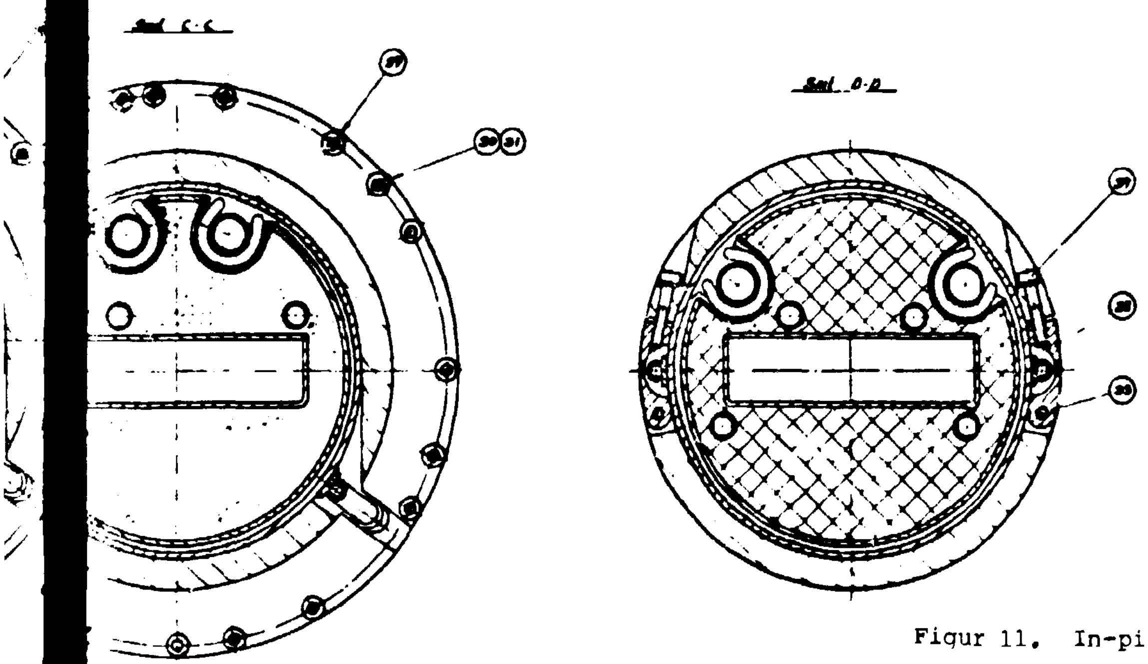
SECTION 2



SECTION 1







SECTION 2

Figur 11. In-pile section of cold source no. 2.

Risø National Laboratory

Risø - M - 2246

Risø - M - 2246

Title and author(s)	Date 1980.09.23
THE COLD NEUTRON SOURCE IN DR 3 Knud Jensen and J.A. Leth	Department or group Engineering
	Group's own registration number(s) 512
30 pages + 2 tables + 11 illustrations	

Abstract

A description of the cold neutron source in DR 3 is given. The moderator of the cold neutron source is supercritical hydrogen at about $30^{O}K$ and 15 bar abs. The necessary cooling capacity is supplied by two Philips Stirling B20 cryogenerators. The hydrogen is circulated between the cryogenerators and the in-pile moderator chamber by small fans. The safety of the facility is based on the use of triple containment preventing contact between hydrogen and air. The triple containment is achieved by enclosing the high vacuum system, surrounding the hydrogen system, in a helium blanket.

The achieved spectrum of the thermal neutron flux and the gain factor are given as well as the experience from more that 5 years of operation.

Finally some work on extension of the facility to operate two cold sources is reported.

<u>INIS Descriptors</u>

COLD NEUTRON, DR 3 REACTOR, GASES, HYDROGEN, NEUTRON FLUX, NEUTRON SOURCES, OPERATION, SAFETY, SPECIFICATIONS

UDC 539.125.5.03 : 621.039.524.46.034.46

Copies to

Available on request from Risø Library, Risø National Laboratory (Risø Bibliotek), Forsøgsanlæg Risø), DK-4000 Roskilde, Denmark
Telephone: (03) 37 12 12, ext. 2262. Telex: 43116